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THAWING BENEATH BUILDINGS CONSTRUCTED ON PERMAFROST NEAR FAIRBANKS, ALASKA

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Introduction

The design and construction of stable foundations for buildings in arctic and subarctic regions present the engineer, conditioned by temperate zone experience, with some very unique and imposing problems. For the most part, these problems are related to the development of methods for preventing thawing below the point of foundation support where such thawing would result in an intolerable amount of subsidence. Where the frozen foundation soils are cohesionless sands or gravels free of segregated ice, the settlement resulting from progressive thawing beneath the building will be negligible. The initial thawing of frozen soils, beneath the point of foundation support, that contain segregated ice, such as lenses, veins, masses, and ice-filled polygon fissures will result in excessive building settlement. Soils that contain segregated ice are generally, but not always, the fine-grained silt and clay soils, or soils containing a substantial amount of silt and clay.

Usually, thawing of sand and gravel foundation soils that explorations indicate are free of segregated ice will not result in an intolerable amount of subsidence. However, appreciable volume change may result from thawing of soils that have no visible segregated ice when the soils are highly compressible in their thawed state, such as soft organic silt,

organic clay, and peat. Determination of the thaw-consolidation characteristics should be made part of a foundation investigation program if such soils are going to be subjected to thawing beneath the elevation of foundation support.

~~This present~~ paper deals with some observations which have been made by personnel of the Arctic Construction & Frost Effects Laboratory to determine the effectiveness of various methods of preventing thawing beneath heated buildings constructed over permafrost. At the Fairbanks Research Area on Farm Loop Road near Fairbanks, Alaska, temperature changes beneath 11 buildings have been recorded for a period of 5 to 8 years; the effects on 4 of these buildings are reported here. Vertical movements of the buildings ~~have~~ also been noted.

Observations of the foundation performance of buildings are now being made simultaneously at several military installations in Alaska and Greenland.

Geography

The following is a brief summary of the climate, soil, and permafrost conditions found in the Fairbanks Research Area.

a. CLIMATE: The mean annual temperature at Fairbanks is about 26°F with extremes of 90° and -55°F. The mean freezing and thawing indexes are about -5680 and 3350 degree-days, respectively. These values are cumulative totals, i.e., the total number of degree-days below 32°F for a mean freezing season of approximately 6 months' duration (October to April), and the number of degree-days above 32°F for a 6-month mean thawing season (April to October). The total annual precipitation is about 11 inches, including an average annual snowfall of about 40 inches.

b. TOPOGRAPHY: The terrain at the Fairbanks Research Area is characterized by a comparatively smooth gentle slope of about 3 percent that generally provides good surface drainage. The original surface cover, cleared in June 1946, was a spruce-birch stand averaging 30 feet in height. This natural cover was replaced by gravel-surfaced roadways, foundation gravel fills, and grass cover.

c. SOIL: The soils underlying the Research Area are principally silts to a depth of about 50 feet with a variable content of organic material and occasional layers of peat. Ice lenses are found throughout the silt, but, generally, the greatest concentration of lenses is found at depths greater than 10 feet. The silt deposit rests on a thick stratum of silty sand and sand-gravel mixtures that extends to a depth of about 250 feet where bedrock is encountered.

d. PERMAFROST: Depth of seasonal thawing under the original wooded cover conditions averaged about 3 feet. The effect of clearing and stripping on thawing is shown in Figure 1. The permafrost surface has degraded to a depth of 6 feet beneath the cleared area, and 9 feet beneath the stripped area. Since the thawed depth does not completely refreeze under the cleared and stripped areas, a condition of degradation has developed.* If the cleared and stripped areas were sufficiently

* Snow cover insulates the ground and limits the freeze-back; this is an important factor in causing degradation. However, the area surrounding the buildings that are discussed here is cleared, and, in some instances, blanketed with gravel fill. Snow removal from the area adjacent to the buildings has promoted complete refreezing of the season's thaw.

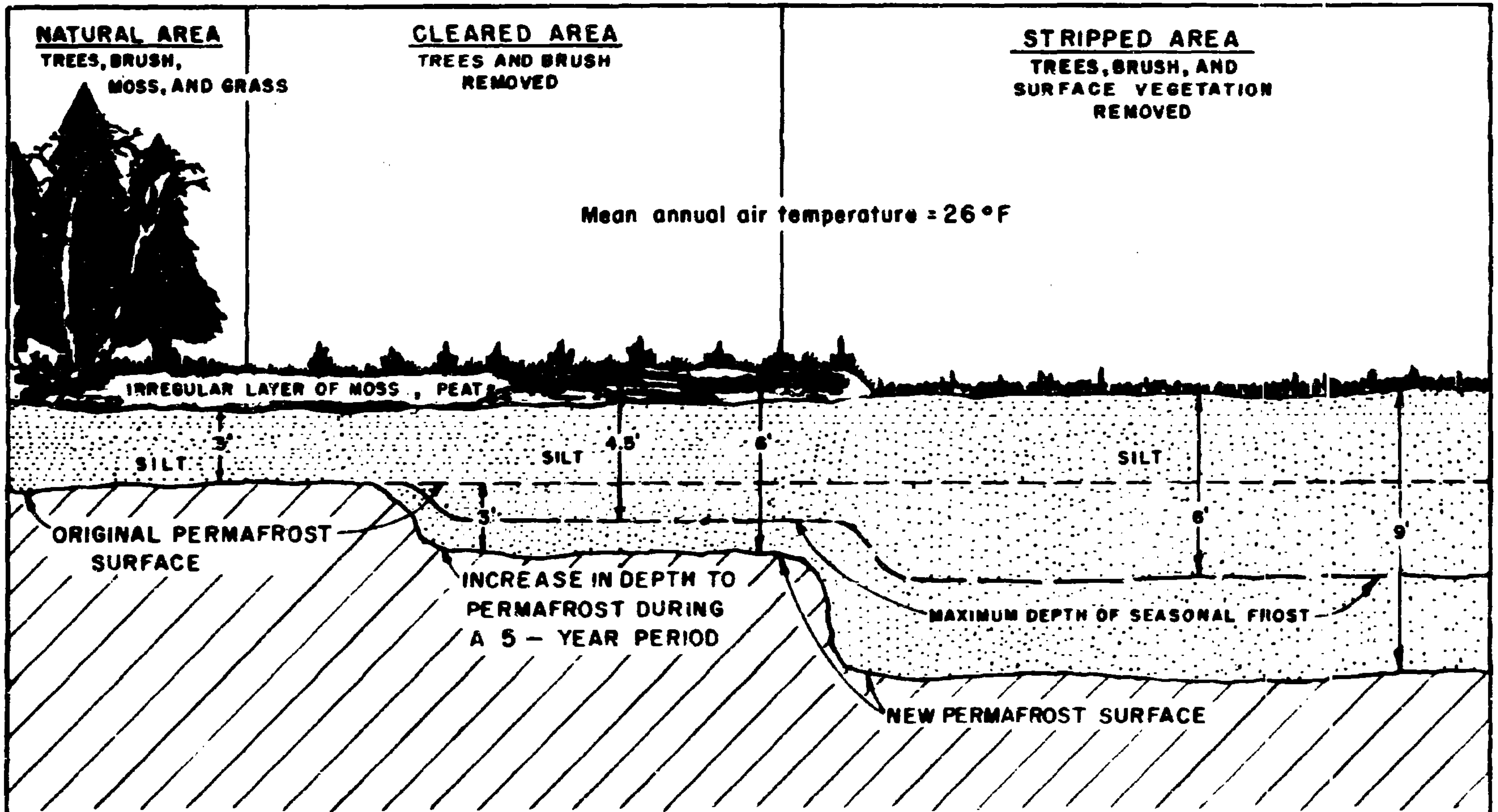


FIGURE I. MEASURED DEGRADATION OF PERMAFROST IN FROST-SUSCEPTIBLE SOILS BELOW DIFFERENT SURFACES IN A SUBARCTIC REGION AFTER A 5 — YEAR PERIOD

large, and if the climatic conditions of the past 5 years were to continue, the entire permafrost layer now 150 to 180 feet thick would disappear over a period of several decades.

Buildings and Foundations

Hence: "What then are the consequences of constructing buildings of various foundation designs on foundation thawing and settlement"?

a. BUILDING NO. 1: Building No. 1, a prefabricated-wood, tar-paper-covered building constructed between July and October 1946, was 16 feet by 16 feet in area with a 4-inch concrete floor slab resting directly on 4 feet of gravel foundation fill, 2 feet of which was below original ground surface. The gravel fill extended 5 feet beyond the building area. The building was heated to an average interior air temperature of 64°F from the middle of October until early in April for 5 consecutive winters starting with 1946-47. The progression of thawing beneath Building No. 1 is shown in Figure 2.

Up to September 1954 when the building was dismantled, the SW corner had settled 18 inches below its original elevation, and differential settlement between NE and SW corners was 9 inches. This resulted in considerable cracking of the foundation slab and separation of floor slab and walls.

b. BUILDING NO. 6: Building No. 6, a prefabricated-wood, tar-paper-covered building 16 feet by 16 feet in area, was also constructed during July and October 1946. The floor slab was insulated, and the foundation had 2-foot high wood posts resting on 10-inch by 18-inch

wood pads, 3 to 6 inches thick, on natural ground without a gravel base. The tops of the wood pads were placed level with the ground surface. The building was heated to the same temperature as Building No. 1, but for only 4 winters since it was not heated during 1950-51. The maximum depth of thaw beneath the building at the end of each thawing period is shown in Figure 3.

It may be seen that there was a general raising of the upper surface of permafrost after construction of the building. The greater depth of thawing that occurred during 1950, as compared with thawing during 1947, 1948, and 1949, is attributed to the unusually warm summer in 1950. The thawing indexes of the Fairbanks Research Area were 3625 degree-days for 1950, and 3065, 2913, and 3072 for 1947, 1948, and 1949, respectively. Yearly freezing records beneath the building showed that the foundation was completely refrozen before the end of December; this gave an ample factor of safety against degradation beneath the building.

The seasonal heaving and subsidence of the building due to freezing and thawing of the active zone ranged between 4 and 5 inches, and with a maximum differential movement of 1.5 inches. This movement which was relatively uniform did not cause any noticeable distortion of the building. The foundation was considered to have given very satisfactory performance for this type of structure.

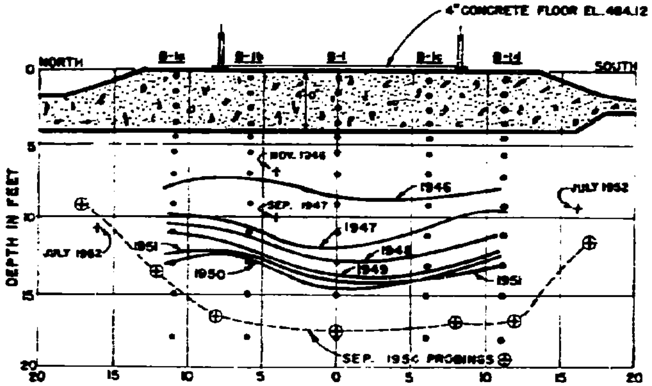
The building was removed during July 1951, and probings made in July 1952 showed the depth of thawing to be greater than at any

time that the building was in place. This indicated that the shading of the ground surface by the building had a beneficial effect in limiting the depth of thawing.

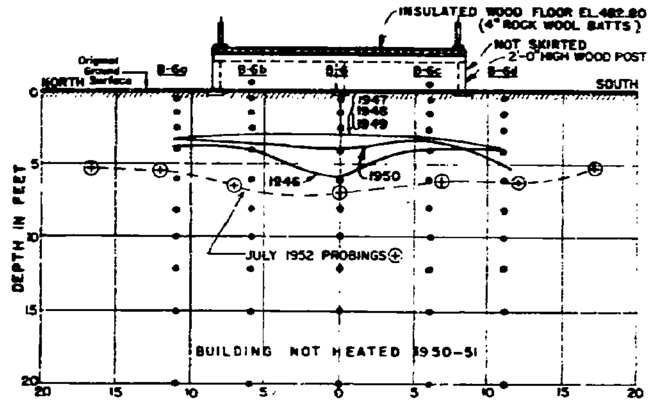
c. BUILDING NO. 9: Building No. 9, a 32-foot by 32-foot wood-frame residence, was constructed between July and December 1947. The foundation is made up of 2 slabs of reinforced concrete separated by 3-foot concrete piers to maintain a 2-foot high airspace (Fig. 4). This foundation was placed on a 5.6-foot thick gravel fill, 5 feet of which extends below original ground surface. The building floor system that rests on the upper concrete slab is insulated. The building has been occupied and heated since construction.

The maximum depth of seasonal thawing is very consistent from year to year on the north side of the building, but seasonal thawing is becoming deeper each successive year on the south side (Fig. 4). It is believed that the lowering of the permafrost table at this location is caused by the concentrated flow of ground water beneath the drainage ditch adjacent to the access road located parallel with the south side of Building No. 9. Probings to permafrost table beneath this drainage ditch indicated a marked channeling of the permafrost surface.

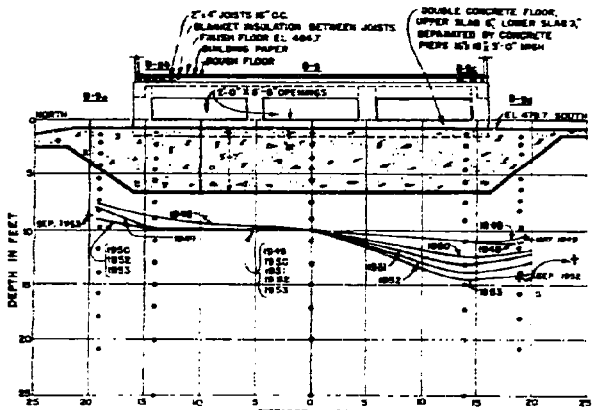
For Building No. 9, the seasonal heave, progressive settlement, and amount of tilt are all only about 1 inch to 2 inches in 6 years of observation. No appreciable structural strain or damage has occurred in the building. The rigid type of concrete foundation in combination with the airspace and gravel fill aided in reducing the differential subsidence and contributed to the excellent performance.



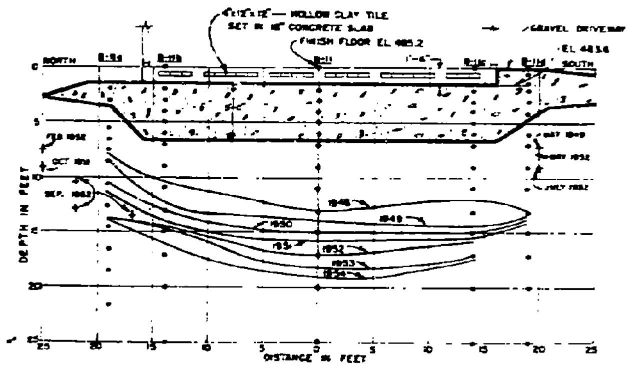
DISTANCE IN FEET
BUILDING NO. 1
(Dismantled Sep. 1954)
FIGURE 2



DISTANCE IN FEET
BUILDING NO. 6
(Removed July 1951)
FIGURE 3



DISTANCE IN FEET
BUILDING NO. 9
FIGURE 4



DISTANCE IN FEET
BUILDING NO. 11
FIGURE 5

LEGEND

GRAVEL FILL, ALL OTHER FOUNDATION SOILS ARE SILT (ML OR ML-CL)

+, ⊕ PROBINGS TO PERMAFROST

1947 SURFACE OF PERMAFROST FROM TEMPERATURE DATA AT END OF THAWING PERIOD FOR GIVEN YEAR

• • MEASURING THERMOCOUPLE POSITIONS

BUILDING NOS 1 AND 6 WERE CONSTRUCTED BETWEEN JULY AND OCT. 1946.

BUILDING NOS 9 AND 11 WERE CONSTRUCTED BETWEEN JULY AND DEC. 1947

DEGRADATION OF PERMAFROST
NORTH - SOUTH BUILDING CENTERLINE
1946 - 1954

d. BUILDING NO. 11: Building No. 11, 32 feet by 32 feet in area, was also constructed between July and December 1947, and has served as a heated garage since that time. The foundation has 5 feet of gravel fill, approximately 4 feet of which is below the original ground surface (Fig. 5). The floor of the building is made up of an 18-inch thick reinforced concrete floor slab with 4-inch by 12-inch by 12-inch hollow clay tiles placed at the mid-depth of the slab. These hollow tiles were intended to permit circulation of outside air through the slab to dissipate the heat flowing through the floor slab from the wood-frame building.

The record of thawing indicates that the hollow tiles in the foundation slab have been ineffective in prevention of progressive foundation thawing (Fig. 5). Thawing at the center of the building had progressed approximately 19 feet below the floor surface by the summer of 1954. During the winters there has been some evidence of freezing of the gravel fill under the edge of the floor slab indicating that cold air is entering through the ends of the tiles. No seasonal freezing has occurred at the interior of the building.

Relatively small displacement occurred in Building No. 11 before the summer of 1950, but then the structure settled each summer and remained practically stationary during the winter months. The settlement has caused pronounced tilting of the structure. The SW corner has settled a total of 18 inches up to the end of the year 1954, and the differential settlement between the NE and SW corner is 12 inches. The progress of thawing and settlement of this building together with soil profile is shown in Figure 6.

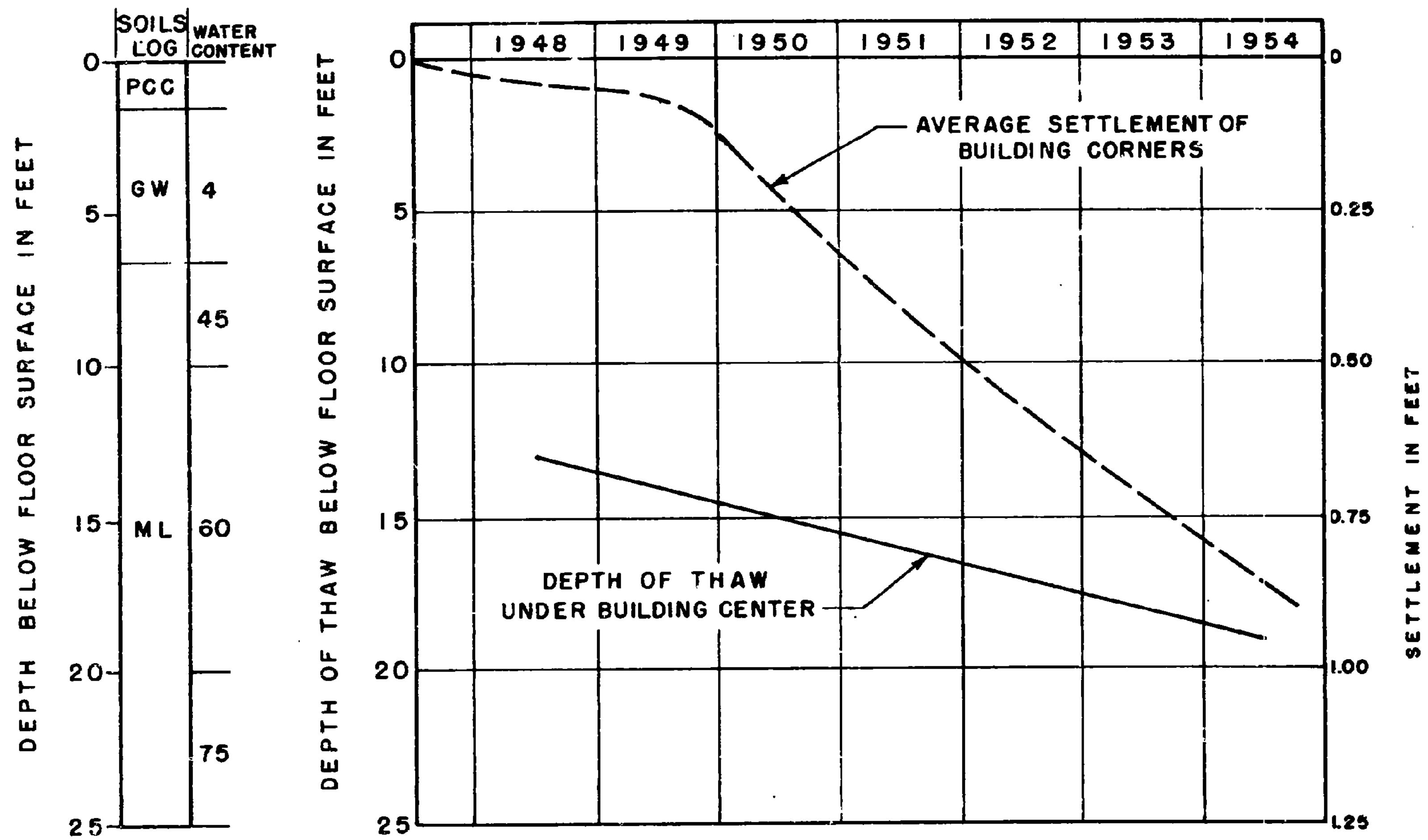


FIGURE 6. DEPTH OF THAW – AVERAGE SETTLEMENT AND TIME FOR BUILDING NO. 11

Conclusion

Observations by personnel of the Arctic Construction & Frost Effects Laboratory of the performance of the foundations of actual buildings and test structures at the Fairbanks Research Area have led toward establishing and improving design criteria for military construction. Theoretical analyses by modern computational methods of the heat flow beneath the building, in which the effect of the various significant variables is studied, permit a better understanding of the problem and allow for wider application of the data in design studies. By this means, the Corps of Engineers is continuously endeavoring to improve methods of providing stable and economical foundations on permafrost.